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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Steam Turbine
Lubricating Oils

PUBLISHED BY
THE TEXAS COMPANY
TEXACO PETROLEUM PRODUCTS

RESISTANCE TO RUST AND OXIDATION

TURBINE oil research in the laboratories of The Texas Company has been a fascinating procedure. It began with the inception of these laboratories. It has been progressively active ever since. Along with the test-tube studies of the petroleum chemist went the service tests in both marine and stationary power plant turbines

Quite naturally, when it was necessary to perfect more effective methods of rendering steam turbine oils more resistant to rust and oxidation, The Texas Company Research Laboratories kept pace. It was fully realized that no matter what the source of the crude or the manner of refinement, straight mineral oils are susceptible to oxidation. Experience proved that the addition of chemicals which will retard and prevent rust and oxidation, is the most effectual way to produce a dependable oil. This was not accomplished in a day. There were thousands of potential anti-oxidants available. Which were the most effectual? Some were petroleum derivatives; others included elements beyond the hydrocarbon range. Obviously the petroleum industry considered its own derivatives first, but it evaulated the others with equal thoroughness.

Evaluation of an additive is an interesting procedure. It begins in the test tube; then progresses to the accelerated oxidation stage where small samples of the proposed mineral oil (already most highly refined) are compounded with a certain amount of additive and subjected to the most severe oxidizing conditions that can be developed. Many were tried but few were chosen.

Those compounds which looked promising were prepared in greater volume and run in actual service. At first the stationary turbines in The Texas Company Refineries were used. Here the research chemist could watch the performance of an oil day by day. He could observe change in neutralization number, take record samples, note operating temperatures, vary these latter judiciously (with the cooperation of the plant engineer), and even add water in excess to note the effect upon the performance of the oil and the reconditioning system. Years of such testing have proved the value of this method.

These better oils were required for all types of modern steam turbines, particularly in naval service. The war accentuated this need.

Texaco Regal Oils R & O (rust and oxidation inhibited) resulted from this research. They fully meet all specifications of leading turbine builders and the United States Navy. Their use should eliminate many of the problems discussed in the accompanying article.

LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

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Steam Turbine Lubricating Oils

SATISFACTORY lubrication of a steam turbine depends upon how dependably the lubricating oil will retain its maximum lubricating ability and how effectually this can be assured in service.

There are several conditions which will affect the performance of the oil. Their relative effect upon any turbine oil will depend upon its degree of refinement. In other words, upon how successfully the petroleum chemist has perfected a method of refinement for the crude oil available, so that the resultant lubricating oil stock will be free from unstable components. It is these unstable components which are most susceptible to oxidation. The function of the refinery process is to remove them as completely as possible.

The conditions which promote lubrication failures, in more or less the order of their occurrence are noted herewith. Any one may develop independently of the others; it depends upon the severity of the cause and the ability of the oil to resist the injurious effects.

EMULSIFICATION, FOAMING, OXIDATION, SLUDGING

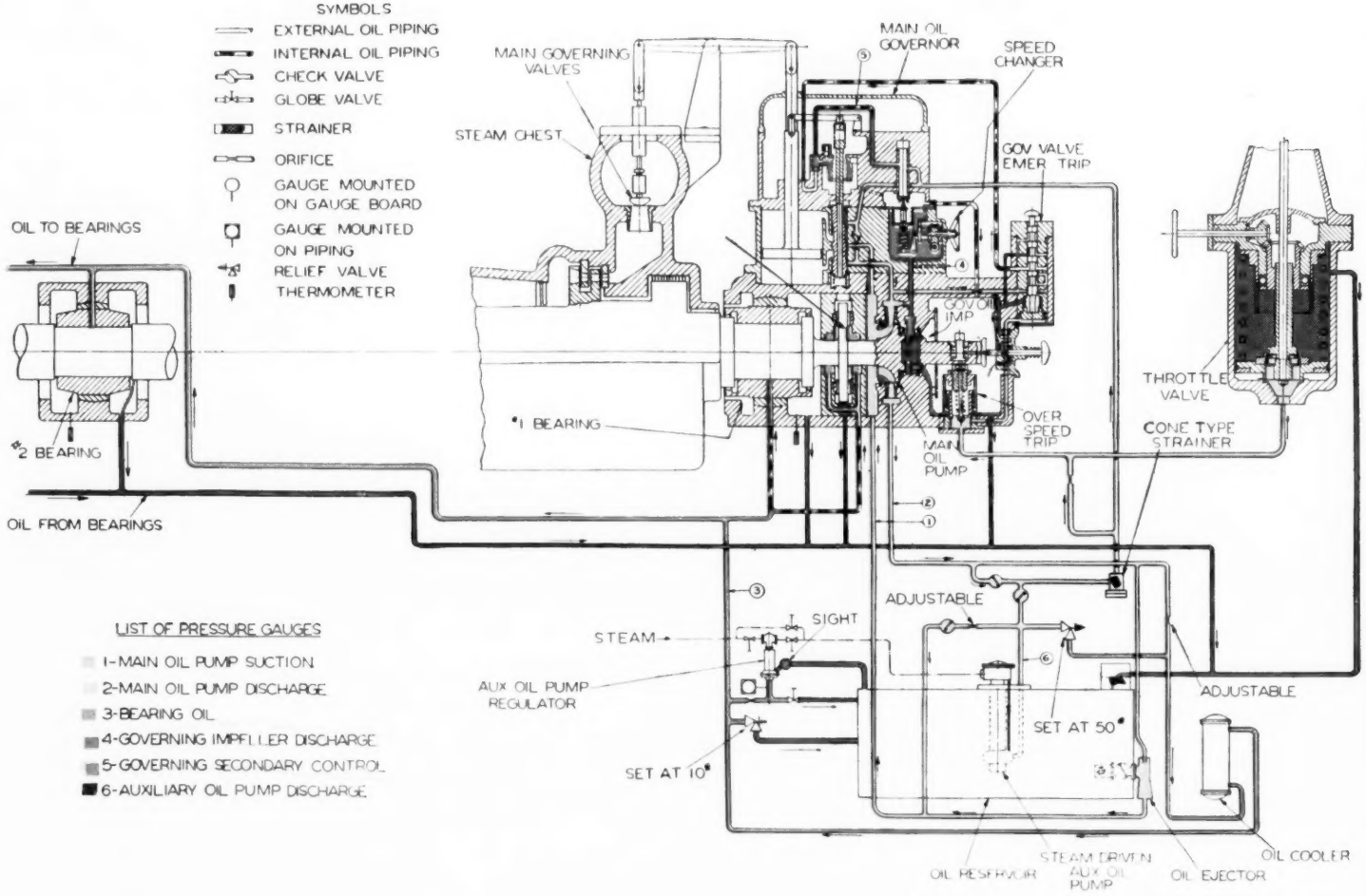
Much has been written about these four phenomena – or should they be called the four "nightmares" – of turbine lubrication engineers, when dealing with present-day straight mineral oils.

The cause can be quoted in generalities – such as excess air, excess water, excess heat, but the effect leads to but one ultimate result: turbine shutdown.

The answer is a lubricating oil which can function under any conditions. Intensive research was necessary to develop such an oil. It meant the modernizing of oils already very successful but not quite satisfactory when super-production of power required higher steam temperatures and turbines "on the line" more continuously. The petroleum chemist met the challenge. Test tube research predicted methods of refinery procedure. The inhibited turbine oils are designed to withstand the conditions discussed in this article.

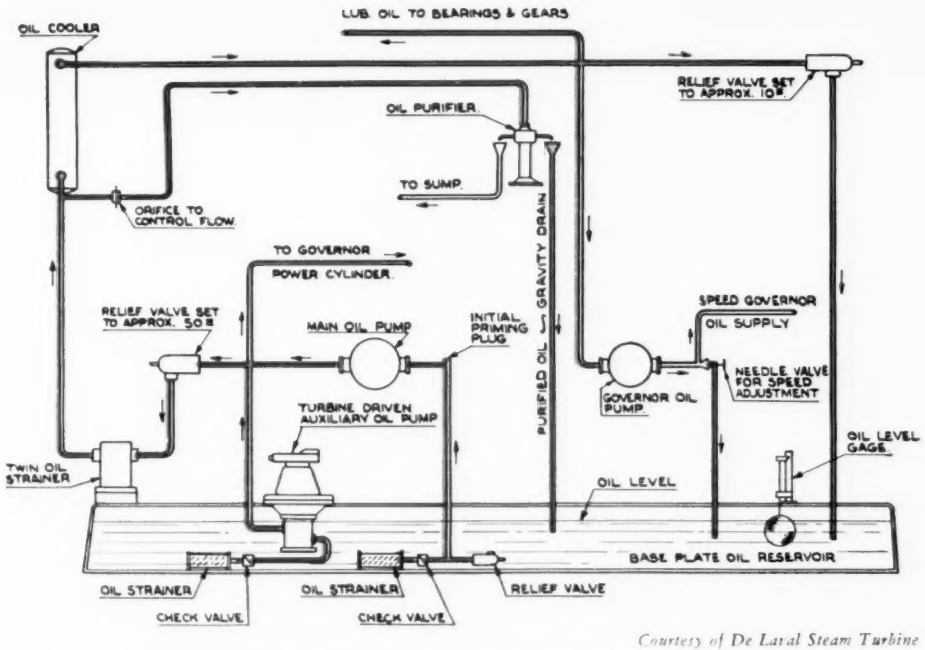
Emulsification and foaming are caused by water, air and other contaminants. They are objectionable but do not always lead to faulty lubrication unless they occur to excess, in the presence of the oxidizing conditions of high temperature, free air circulation and metallic contamination of the oil.

Oxidation and sludge formation, however, can definitely be the cause of serious lubrication difficulties, even to the extent of ruined bearings, scored shafting and machinery tie-ups.



Courtesy of Westinghouse Electric and Manufacturing Co.

Fig. 1–Details of a typical Westinghouse steam turbine oiling system.



Courtesy of De Laval Steam Turbine Company

Fig. 2—A typical closed pressure oiling system for a De Laval geared turbine-driven water works pump.

EMULSIFICATION AND DEMULSIBILITY

Turbine bearing lubricating oil circulates at a rate of around 400 gallons per minute in average power plant service. The lubricating system is designed to prevent excessive surge and normally the volume of oil in reserve is sufficient to allow of an ample period of rest before recirculation. And yet, there is sufficient turbulence to enable an oil-water emulsion to persist if the oil emulsifies readily and water is present. As emulsification is one of the contributing factors in sludging, the oil should be resistant to emulsification, and such emulsions as may form should separate readily. This is denoted by the demulsibility.

Petroleum chemistry defines an emulsion as a very intimate mixture of liquids which are insoluble or only slightly soluble in each other, the mixture being so stable and the liquids so mutually held in suspension that separation due to differences in specific gravity or density is very slow.

AVAILABLE VISCOSITY RANGES

Experience has indicated that well-defined viscosity ranges are practicable. For the modern, high-speed steam turbine directly connected to an electric generator, the range is from 140 to 250 seconds Saybolt Universal at 100°F. This range in turn is sub-divided so that two oils are available. One within the lower limits, i.e., having a viscosity of from 140 to 170. The other within the higher limits, with a viscosity of from 175 to 250.

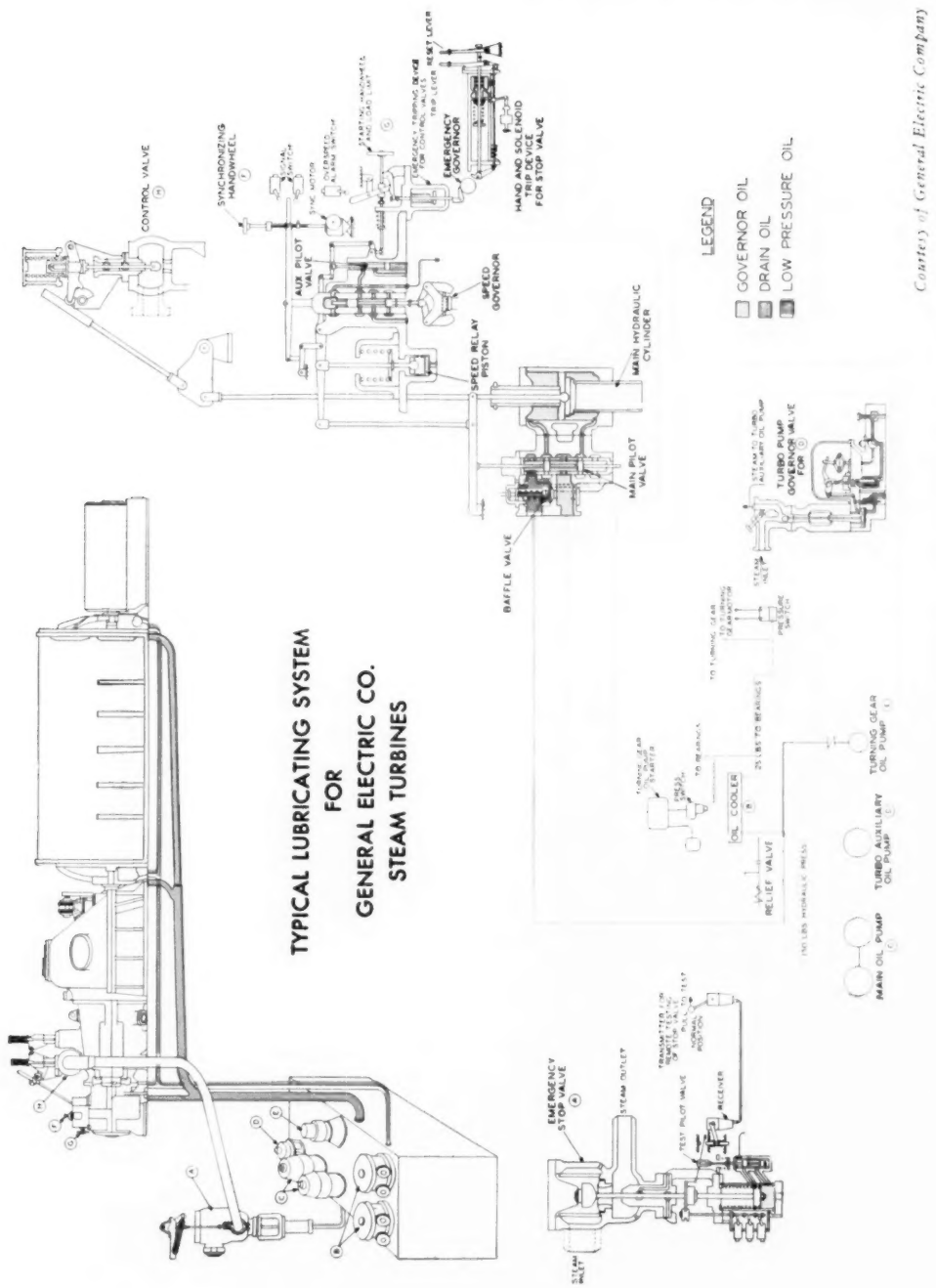
Where the turbine must be geared down to propeller shaft speed, as in many marine installations, a higher viscosity is necessary if the oil must serve the dual purpose of lubricating not only the bearings but also the gears. To meet these conditions the Saybolt viscosity range is from around 250 to 550 seconds at 100°F. Here again the range is sub-divided to provide an oil around the lower limit — from 250 to 350 seconds; and one within the higher range — from 400 to 550 seconds. These approximate ranges are in line with the turbine builders individual specifications and enable the operator to effectively meet his service conditions.

FOAMING

Foaming indicates that air is being retained by the lubricating oil. It is: unsightly, dangerous, wasteful, impedes oil flow to bearings, causes erratic action of the governor.

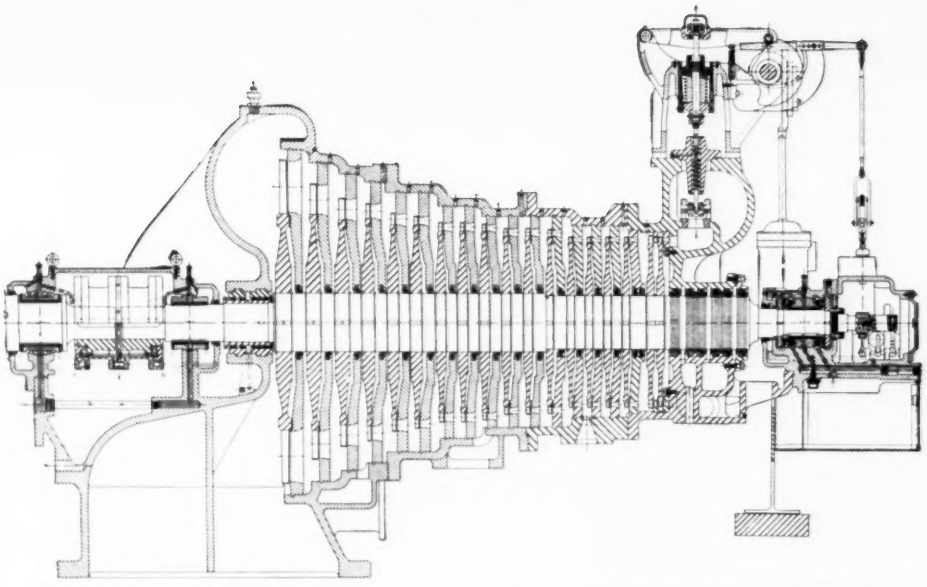
Any petroleum oil will take up air. Lighter bodied oils free themselves of air more readily than heavier oils. All will persist in taking up air (some more actively than others) as long as conditions favorable to this action prevail. These conditions are mainly mechanical and dependent upon maintenance. They include:

a. Air leakage into the oil pump suction line.
b. Low oil level, permitting the pump suction inlet to become exposed.



Courtesy of General Electric Company

Fig. 3.—A typical General Electric steam turbine showing details of the high and low pressure sides of the oiling system.



Courtesy of Worthington Pump and Machinery Corporation Moore Steam Turbine Division

Fig. 4—Section through a Worthington-Moore Multi-stage steam turbine. Red denotes the lubricating system.

c. Insufficient venting of the lubricating system.
d. Excessive drop from oil return lines to sump.
e. Oil return lines of insufficient size or capacity.
f. Discharge velocity from pressure regulating valve too high.
g. Contaminated oil.
h. Running the pump at excessive capacity.

Maintenance is responsible for the correction of these conditions. Maintenance is also responsible for the manner in which fresh oil is added. This can be another cause of foaming. Wide differences in temperature between the fresh oil and the oil in the system also contribute.

Correcting the Cause

It is obvious that since the several causes of foaming relate to design or method of operation, the correction should be approached accordingly. Normally, the cause can be located by the process of elimination; sometimes however, where the condition is particularly aggravating, air may be entering the system at more than one point. Even then, the observant operator can be relied upon to apply means of correction which are not too costly, and certainly, worth-while in protecting the durability of his oil.

EFFECT OF OXIDATION

Oxidation is today regarded as probably requiring the most consideration among the factors which may influence the demulsibility of an oil.

All mineral oils will be subjected to more or less oxidation when agitated with water at normal operating temperatures in the presence of air. The rate of oxidation is known to roughly double with each increase of about 20 degrees Fahr. in temperature of the oil, other conditions being the same.

Wherever particles of air and water are suspended or retained within the body of an oil to form an emulsion, in some cases only a slight elevation of temperature during circulating or agitation may be necessary to bring about an appreciable oxidizing reaction between the air and oil, due to the catalyzing or "speeding up" effect of these contaminants.

Conditions responsible for oxidation are normally so involved and so contingent upon one another that no one of them can be rightly claimed as being more detrimental than the other. On the whole, however, it may be stated that the extent to which oxidation of unhibited oils will occur depends largely upon the refinement of the original oil. In other words, certain petroleum hydrocarbons will oxidize more readily than others. Logically, it would be advisable to bend every effort in the refinery to effect the removal of these components by careful refining. The more reliable the manufacturer, naturally the more dependence can be placed on his methods of refining.

Metallic Particles Promote Oxidation

Oxidation requires air; it is accelerated by the effect of certain metals, especially copper, brass, bronze, and iron; or foreign matter such as dust, dirt and moisture. In fact, in an already emulsified oil, foreign matter of this nature is regarded as being the co-partner of oxidation in producing the

Oil Film Rupture

Oil film rupture is synonymous with film breakdown; if allowed to develop to excess it may cause actual metal-to-metal contact between a turbine journal and its companion bearing.

The causes are of interest, in that, almost without exception, they can be prevented by careful maintenance and supervision. To accomplish this we must consider:

(a) *Entrained Air:* This is a direct result of abnormal leakage of air into some part of the system. It is the primary cause of foaming. Supervision which will lead to the detection of air leaks is the obvious way to correct this difficulty. This has been discussed in more detail under the subject of foaming.

(b) *Entrained Water:* This involves leakage of water into the oiling system which so often may result in emulsification of a considerable part of the oil in service. Here again supervision and maintenance are necessary to eliminate water leakage at the source.

(c) *Insufficient Oil:* Entrained air and water which contribute to emulsification also may reduce the delivery of oil to the bearings. Other causes of insufficient oil are restrictions in the circulating system due to deposits of sludge or foreign matter in the piping.

(d) *Insufficient Viscosity:* This may be due to too high bearing temperatures or too low an initial viscosity for the load and peripheral speed imposed on the bearing. This may develop during the periods of starting and stopping in some turbines, or where a rolling gear is installed to turn the turbine over at low speeds. On such occasions, the oil must have sufficient viscosity and wettability to insure maintenance of an adequate film between the contact surfaces.

resultant insoluble sludges so detrimental to proper lubrication.

It is believed by some that if an emulsion is prevented, sludging will be greatly lessened. But emulsion involves only oil and water. It would, therefore, seem logical to consider foreign matter, or the catalyzers such as metallic particles which promote oxidation, as an equal detriment.

Emulsions alone are certainly not so viscous, adhesive, and generally objectionable as insoluble sludges which frequently clog oil passages, congest the oiling system, and generally reduce the lubricating quality of the oil.

The natural procedure is, therefore, to reduce the effect by removing the cause as far as possible; in other words by purifying the oil during operation to a sufficient degree to practically eliminate water, emulsion, and foreign matter preferably as rapidly as it is introduced.

SLUDGE FORMATION – THE RESULT OF OXIDATION

Sludge, as it may be developed when a turbine oil is agitated in the presence of air or water, especially under overheated conditions, is formed in two stages, viz:

The colloidal or soluble stage, which is more or less of a primary development, and

The insoluble stage wherein the sludge becomes permanent in form.

In the colloidal stage if water is present a fairly stable emulsion may result. On the other hand, the presence of an emulsion is not necessarily indicative of colloids. Both emulsions and colloidal sludges are relatively temporary at normal operating temperatures.

Emulsions, if uncontaminated and unoxidized, will clarify themselves and precipitate water on standing, leaving the bulk of the oil in very nearly the same condition as prior to agitation. Such emulsions also can be separated by centrifuging.

Colloidal sludges (or, as they may be termed, soluble sludges), in turn, at temperatures above approximately 100 degrees Fahr., will be more readily absorbed by the oil. On the other hand, while present they may be a detriment to lubrication, due to the fact that the formation of a continuous, uniform oil film over the surface to be lubricated may be impaired.

Where oxidation in an oil has occurred, it will interfere with the separation of contaminating foreign matter. As a consequence, this latter will exercise its catalyzing effect on further oxidation to cause permanent sludges.

Where colloidal sludges have passed over to the state of insolubility, immediate steps should be taken to correct this by the removal of the heavy, adhesive, and relatively solid matter from the system, otherwise lubrication will be bound to be impaired. The conditions responsible for the formation of these sludges should be determined and remedied.

THE EFFECT OF WATER

The detrimental effect of water has already been mentioned in discussing oxidation, emulsification, and sludge formation. If a turbine and oiling system could be so designed as to eliminate the chances of water leakage or condensation occurring, there would be but little emulsion developed, provided the original oil was water-free.

It must be assumed, however, that the presence of a certain amount of water and other impurities is a certainty. As a result, emulsions and sludges will tend to form in the average turbine oiling system. Effective purification should bring about the removal of these before their proportion becomes dangerous. From a constructional viewpoint, therefore, a turbine oiling system should be so designed as to permit of ready separation of impurities from the oil by the reconditioning apparatus.

Where the oil is in a sufficient state of purity, separation from water will normally occur comparatively readily, for the emulsion caused by agitation will be of relatively temporary character.

WHAT HAPPENS IN THE OILING SYSTEM

Used turbine oils must be studied according to the conditions which have caused them to become contaminated:

1. Deterioration due to oxidation in the presence of air (or other oxygen containing media), accompanied by high temperature service. Products of oxidation may be soluble or insoluble in the used oil.
2. Deterioration due to polymerization (physical linkage of like oil molecules causing oil thickening), resulting from high temperature service. Products of polymerization may be soluble or insoluble in the used oil.
3. Contamination with extraneous foreign matter. Products of contamination include:
   (a) Dirt and dust common to the region where the turbine operates.
   (b) Core sand that has remained in bearing or pedestal castings from the time they were poured in the foundry.
   (c) Metal particles remaining from the time any part of the turbine bearing oiling system was in the repair shop.
   (d) Metal particles due to disintegration of bearing metals.
   (e) Rust.

DESIGNING FOR RESISTANCE TO RUST AND OXIDATION

The development of turbine oils which would be resistant to rust and oxidation quite naturally was dependent upon laboratory research. First the chemist had to perfect his methods of test and extend his evaluations of crude oil sources. Then he studied the applicability of the various available additives one by one. Following this, exhaustive field testing was necessary. The conditions under which the oils had to function were known; to predict the ability of any oil to meet these conditions required volumes of check data.

Until recently laboratory methods of evaluation were inadequate. That this was recognized both by turbine manufacturers and the petroleum industry is evidenced by the extensive work carried out by a committee of The American Society for Testing Materials, and by the support given this group by all concerned. The leaders in the petroleum industry took an active part in this work and they are cooperating still further in improving the rusting, oxidation and emulsion tests. Many valuable suggestions have been contributed to this committee. As a result of this work better tests are now available for evaluating the rust inhibiting properties and oxidation stability of turbine oils.

But, even though laboratory tests are very useful in developing new products, the ultimate criterion is satisfactory performance in the field. The question of field testing has been given adequate consideration in the present development, as will be brought out hereafter.

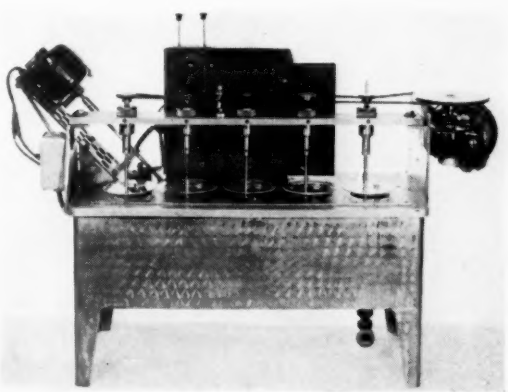


Fig. 5—The A.S.T.M. Rusting Test Bath.

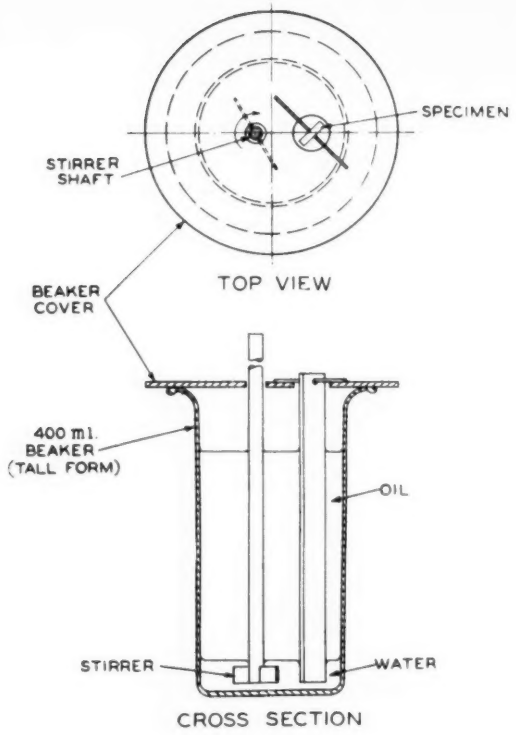


Fig. 6—Details of the A.S.T.M. rusting test set-up.

RESEARCH AND DEVELOPMENT

What are the desirable properties of a modern turbine oil? What are the important criteria of performance in the lubrication of turbines, including those of the marine type? The answers to these questions have been suggested earlier in this article. It is well to repeat, however, that:

1. The oil must lubricate bearings and gears adequately.
2. It must retain its lubricating properties over a wide range of temperatures.
3. It must show excellent resistance to oxidation and sludging.
4. It must prevent the rusting of turbine parts, even in the presence of sea water.
5. It must be non-corrosive to bearings or turbine and engine parts.
6. Water should separate from the oil rapidly and completely by the means available.
7. Tendency toward foaming should be at a minimum.
8. Storage should not cause deterioration in its properties.
9. The oil should satisfactorily lubricate auxiliary equipment, such as internal combustion engines, air compressors, etc., should it be necessary, particularly on ships, to use turbine oil for such equipment in an emergency.

Highly refined straight mineral oils meet all the above requirements, with the exception that they do not prevent rusting, particularly in the presence of water, nor have they sufficient resistance against oxidation under severe conditions of operation. In the development of rust and oxidation inhibited oils, therefore, the problem was to impart rust inhibiting properties and oxidation stability to the available base oils without harming other desirable characteristics.

Rust Prevention

While many theories have been advanced to explain the action of rust inhibitors, the most plausible is that the inhibitor, which has been added to the turbine oil, "plates out" on the metal surfaces of the turbine, forming an oily film which is impervious to the rusting action of moisture and air. Gradually in the course of service, uninhibited turbine oils appear to develop "natural inhibitors," which seem to greatly retard rust formation.

At the beginning of this research very little information was available concerning the types of compounds which could be used in turbine oils as rust inhibitors. Many materials known to be effective were found to adversely affect one or more of the other necessary properties of the turbine oil; for example, they made the oil emulsify readily, oxidize rapidly, foam, etc. Hundreds of compounds were tested. Several were found which afforded satisfactory protection against ordinary water, but not against sea water.

After months of concerted effort, however, the answer was finally obtained in the form of certain synthetic compounds which afford protection even against salt water. The type of additive found to be necessary had to have a very strong affinity for metal. Many compounds of this type tend to emulsify and retain water in suspension; an undesirable property. Some, however, have been found which are free from this drawback, even assuring excellent protection against sea water corrosion.

The problem was solved.

Oxidation Stability

The theory underlying the effectiveness of turbine oil oxidation inhibitors may be outlined briefly as follows:

1. Oxygen, which is present through aeration, reacts with oil through a "chain reaction" to form undesirable sludge and acidic materials.

2. In the presence of metals and water this reaction with oxygen is greatly accelerated or catalyzed.
3. Certain chemicals when added to the oil slow down oxidation by reacting with oxygen and breaking the chain reaction, and also by deactivating the metal catalysts.

Here again the literature lists innumerable compounds which are claimed to be anti-oxidants. In general these are ineffective, however, or only slightly effective, under conditions existing in a steam turbine. Most of the rules that years of research had established for predicting the ability of a material to function as an anti-oxidant were therefore of little value. Starting from scratch, as in the case of rust inhibitors, it has been necessary to test many compounds over a period of years before oxidation inhibitors satisfactory for use in premium turbine oils were at last found.

This problem was solved.

Effect of Inhibitors on Each Other

As a result of patient and concentrated research all the constituents for a superior turbine oil were now available — a good base oil, a highly effective rust inhibitor and an excellent anti-oxidant. Would the rust and oxidation inhibitors be effective when used together or would they counteract each other's valuable properties?

Further research on combinations of the inhibitors have proven that when proper selections have been made, the rust inhibitor still prevents corrosion, and the oxidation stability can be not *merely as good*, but actually *better* than that of the oil containing only the anti-oxidant.

DESIGN OF TESTING DEVICES

The A.S.T.M. Rusting Test

As was pointed out heretofore, everybody concerned recognized the need for suitable testing devices for evaluating turbine oils. After considerable cooperative effort, the "A.S.T.M. Rusting Test" was developed (A.S.T.M. Designation D665-42T, Rust Preventing Characteristics of Steam Turbine Oil in the Presence of Water).

In this test carefully prepared steel strips are suspended in a mixture of the oil under test and ten per cent water, which is agitated rapidly for 48 hours at a temperature of 140°F. In order for the oil to be considered satisfactory the specimen must show no rusting at the end of the test.

A unit for carrying out five tests simultaneously is shown in Fig. 5. Details of a single test set-up are shown in Fig. 6. The same equipment is used for the Sea Water Rusting Test and the Film Tenacity Test, described below.

Sea Water Rusting Test

The Sea Water Rusting Test is carried out in the same way as A.S.T.M. Test No. D665-42T except that ten per cent of a solution of a composition approximating that of sea water is used instead of distilled water.

The composition of the synthetic sea water, is given in United States Navy, Bureau of Ships, Specification 14-0-15 (INT), dated March 1, 1943 covering Turbine Lubricating Oil, Non-Corrosive, (Symbol 2190-T):

	Grams per litre
Magnesium Chloride: $6H_2O$	11.0
Anhydrous Calcium Chloride	1.2
Anhydrous Sodium Sulfate	4.0
Sodium Chloride	25.0

The Salt Water Rusting Test is one of the requirements of the above Specification.

The Shell Film Tenacity Test

The Shell Film Tenacity Test was developed by the Shell Oil Company Laboratories as a supplement to the A.S.T.M. Rusting Test (distilled water). As its name implies, the test indicates the

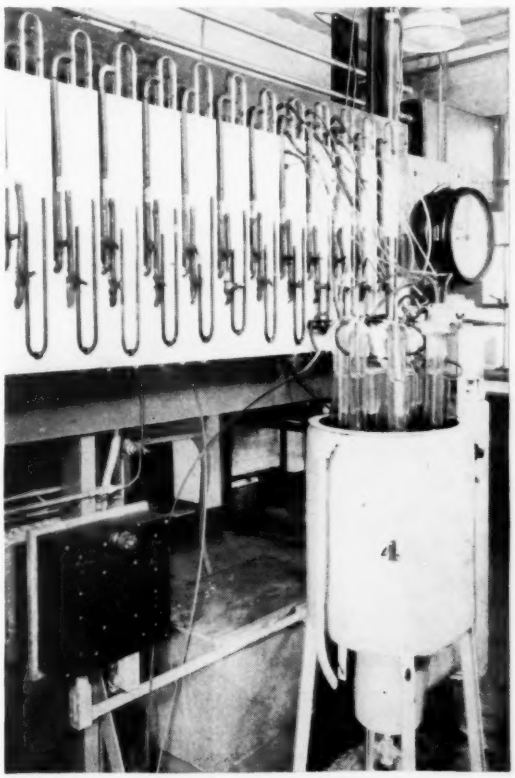


Fig. 7—A.S.T.M. oxidation tests in progress showing bath, flowmeters, temperature recorder, etc.

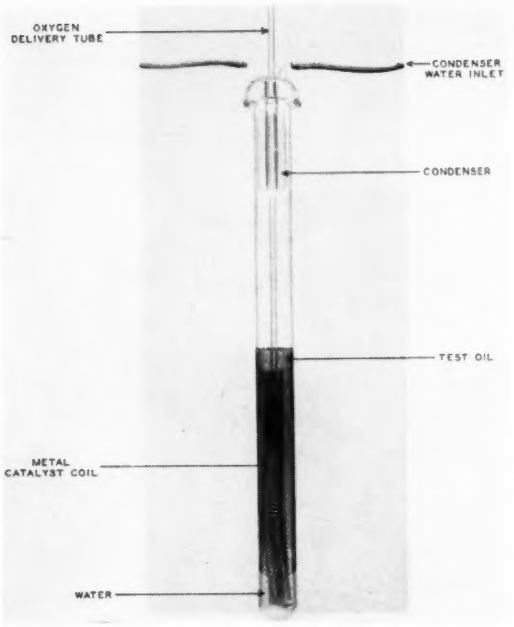


Fig. 8—A.S.T.M. oxidation test set-up.

tenacity or persistence of the protective film formed by rust inhibiting additives. It is run by placing test strips which have successfully completed the A.S.T.M. Rusting Test into beakers containing water instead of oil, and agitating for 24 hours at 140°F. To pass the test the specimen should show no rust at the end of 24 hours.

The Navy Corrosion Test

An additional rusting test at one time recommended by the United States Navy requires that a mild steel specimen shall show no rust at the end of *500 hours'* contact with a mixture of the oil and ten per cent water at room temperature. The mixture is agitated by the specimen itself, which is rotated at 1200 r.p.m.

The A.S.T.M. Turbine Oil Oxidation Test

Figs. 7 and 8 show equipment used in carrying out the A.S.T.M. Oxidation Test for Turbine Oils. The oil is oxidized at 203-205°F. with oxygen in the presence of water and a copper-iron catalyst. The "life" of the oil is arbitrarily taken as the time required for the neutralization number (a measure of the organic acidity developed through oxidation of the oil) to reach a value of two.

The MacCoull Corrosion Test

Because it is sometimes necessary to use turbine oils in internal combustion engines, it is important to know the corrosiveness of the oil to bearings. A simple means of measuring this property is by the MacCoull Corrosion Test, developed by The Texas Company, wherein a bearing is rotated around a steel shaft while lubricated with the test oil at either 250 or 350°F. The bearing is cleaned and weighed every two hours. The weight loss at the end of ten hours is a measure of the corrosiveness of the oil. Although copper-lead bearings are ordinarily used, since this is the most common type of heavy duty bearing, other bearing metals may be substituted if desired. The usual effect of corrosion is the removal of lead or cadmium from a bearing by solution if the bearing composition is favorable to such action. The usual babbitt turbine bearings are not susceptible to oil corrosion.

EVALUATION OF TEST DATA

Rusting Test Results

A picturization of the A.S.T.M. Rusting Test data is shown in Figures 9 and 10.

Figure 9 shows the rust inhibiting properties of a satisfactory rust-resistant turbine oil (Oil E) as compared with a straight mineral turbine oil, using distilled water. In this test, which is, of course, less severe than the salt water test, the former forms no rust, while the uninhibited oil rusts heavily.

Figure 10 shows how the same two oils compare by the rusting test using synthetic sea water at 140°F., and also with three other oils by this same test, (Nos. 2, 3, and 4, all inhibited). It will be observed that, in the very severe salt water test, Oil E gave no rust whatsoever, while a typical present-day straight mineral turbine oil rusted badly. Oil E also was considerably superior to Oil No. 2, definitely better than Oil No. 3, and slightly better than Oil No. 4. The latter oil, however, has poor oxidation stability as will be mentioned later.

Evidence that steel exposed to Oil E is given rust protection of great durability is furnished by the Shell Film Tenacity Test. When a specimen from the A.S.T.M. Rusting Test, using either distilled or synthetic sea water, is subjected to the Film Tenacity Test no rusting occurs in over 100 hours although the test only requires no rust after 24 hours.

The practical significance is that once the metal parts of a turbine come in contact with Oil E they acquire a protective film which persists even though the particular part may subsequently be in contact with water due to trapping of water in the system, etc.

Oxidation Test Results

Figure 11, shows how the oxidation stability of Oil E compares with that of a straight mineral turbine oil; also with certain other inhibited oils. It will be noted that Oil E takes more than 20 times as long to develop a neutralization number of 2.0

as a straight uninhibited oil. Oil No. 2 also has a life of 1,500 hours plus, but, as already mentioned, its rusting properties were relatively poor. Oil No. 3 is definitely inferior to Oil E in oxidation properties, while Oil No. 4 is no better than the uninhibited straight mineral oil.

Figure 12 gives visual proof that Oil E resists oxidation much better than a straight mineral turbine oil as evidenced by the fact that the former is only slightly darkened after 870 hours in the A.S.T.M. Test, while the latter was very dark after only 72 hours.

The laboratory test results should not form the basis for the inference, however, that Oil E will give 20 times longer service than straight mineral turbine oils in units where the latter have been giving satisfactory service for long periods. The results should be interpreted rather as indicating that Oil E will show much longer life under those conditions where straight mineral turbine oils have oxidized rapidly and had to be changed frequently. It should be expected, however, that even in those operations where long life is obtained when using straight mineral oils, the inhibited oils due to rust prevention and anti-oxidation properties should give greater freedom from rust and cleaner systems requiring less maintenance year by year.

Neutralization Number

The neutralization number of turbine oils tends to rise in service. The extent of rise will depend upon the operating conditions and the oil used. Naturally, the rate of neutralization number rise — with even the best of turbine oils — will vary from unit to unit. In some units the neutralization number may rise to 3.0 in a matter of a few months while in other units the rise may be only a fraction of that after many years of service. Hundreds of turbines are operating on turbine oils whose neutralization numbers range anywhere from 0.5 to 3.0 and above after several years of service.

Turbine oils which are resistant to oxidation will show a considerably lower rate of rise in neutralization number in service than straight mineral turbine oils. Yet the initial neutralization number of R and O oils* may be very slightly higher than with certain straight mineral oils. The traditional manufacturing limit on the neutralization number is, however, the same for both types of oils; namely, a maximum of 0.10 mg. KOH/gr. oil which is considered technically acid free if there is *no* mineral acid present, or determined separately.

The slightly higher initial neutralization number of certain rust and oxidation resistant oils is due to the rust inhibitor; and yet, it is interesting to note that during the first few months of service the neutralization number of these oils often decreases due to plating out of the rust inhibitor on the metal surfaces.

*Rust and oxidation resistant.

Engine Tests

In addition to its suitability as a turbine oil, Oil E was also proved to be applicable in *emergencies* for short periods of time as a crankcase lubricant for internal combustion engines. Actual tests included runs for 100 hours in both General Motors single cylinder Model 71 and Atlas-Lanova Diesel engines with satisfactory results.

This same oil also proved satisfactory in the Chevrolet 36-Hour Corrosion Test which is designed to evaluate heavy duty gasoline and Diesel engine lubricants. The results showed that Oil E was of about the same degree of corrosiveness as an uninhibited solvent refined motor oil. In other words this test substantiated the fact that Oil E can be used for emergency lubrication of a gasoline or Diesel engine if necessary.

MacCoull Corrosion Tests at 250°F. and 350°F.

Additional evidence that Oil E is at least as

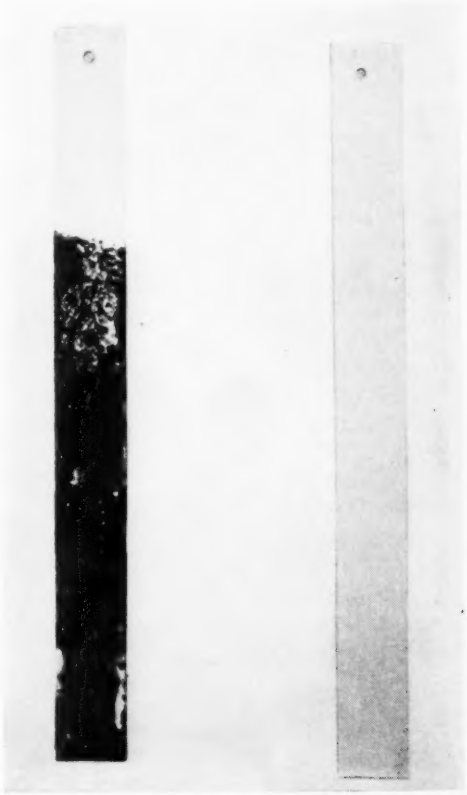


Fig. 9—A.S.T.M. rusting test specimens using distilled water. Strip at left coated with straight mineral turbine oil. Strip at right coated with inhibited turbine oil E, referred to in text.

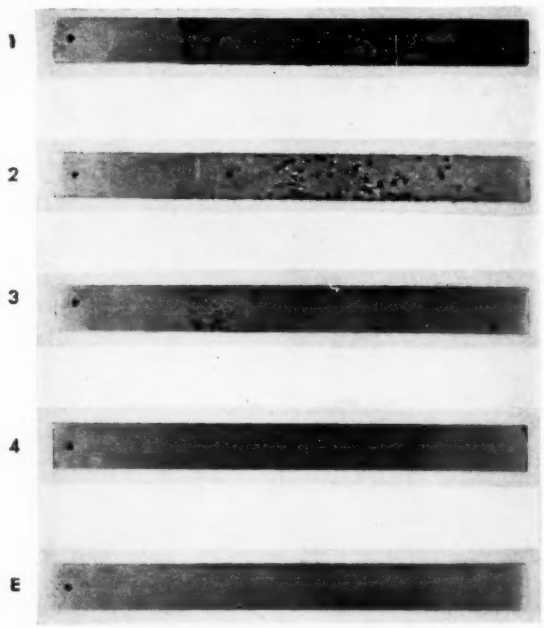


Fig. 10—A.S.T.M. rusting test specimens using synthetic sea water with:
1. A typical straight mineral turbine oil.
2, 3 and 4. Three conventional inhibited turbine oils.
E. Inhibited turbine oil E, referred to in text.

good as uninhibited base oils as to its corrosion characteristics is furnished by the MacCoull Corrosion Test. At 250° F. there is almost no loss in weight of the copper-lead bearings with either Oil E or ordinary mineral turbine oil. At 350° F., however, the improved oil shows considerably less corrosion than the uninhibited oil.

In addition to the above data on copper-lead bearings, MacCoull Tests at 350° F. have also been run on Oil E using F-23 metal bearings. This is a high lead bearing metal used by certain turbine builders on account of emergency war conditions. These tests showed Oil E to be non-corrosive to this type of metal under the conditions of the test.

Compatibility

From the information available on present conventional rust and oxidation resistant turbine oils it is considered probable that no difficulties will be encountered in mixing these products either together or with straight mineral turbine oils.

Storage Stability

It was mentioned that a rust inhibited oil such as Oil E plates out a protective film on metal surfaces. This brings up the question as to whether such an oil can be handled in metal drums without losing its rust inhibiting properties. Accordingly, storage tests of 23 weeks duration in metal drums were made. Subsequently, the oil satisfactorily passed the Sea Water Rusting Test showing that the product can be handled in metal drums without difficulty. In other words, the amount of inhibitor plating out in the drums is infinitesimal in relation to the amount present in the oil, since only a very minute film of molecular dimensions plates out. This small amount results in adequate rust protection.

CLEAN OILING SYSTEMS IMPORTANT

In New Turbines

It is of the utmost importance that prior to charging a *new* turbine with oil, the entire lubricating system should be cleaned and flushed to remove all traces of foreign material (mill scale, rust, welding beads, metal chips, etc.) present, as a result of fabrication and assembly. A number of serious rusting complaints in new turbine ships have been traced to incomplete cleaning and flushing. Rust and other foreign matter had probably been in the systems all the time, thus giving a false impression that the oil had been the cause.

Cleaning a Used System

This applies equally as well to used systems. The performance of turbine oils in service depends to such a large extent on the condition of the lubricating system in which the oil is used that the necessity for having a turbine lubricating system in clean condition before adding a new charge of oil cannot be over-emphasized. Loose mineral matter such as rust and scale will cause clogging of lines, sticking of governors, scoring of journals and bearings: this material also will cause foaming, promote emulsification with water and catalytically accelerate oxidation. Other foreign materials such

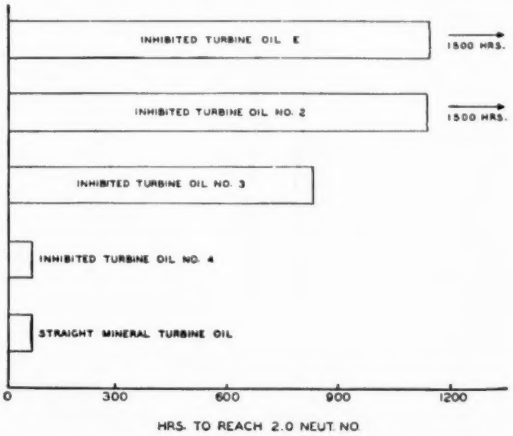


Fig. 11—Oxidation stability comparison by A.S.T.M. oxidation test of inhibited turbine oil E with the several other oils referred to in the text.

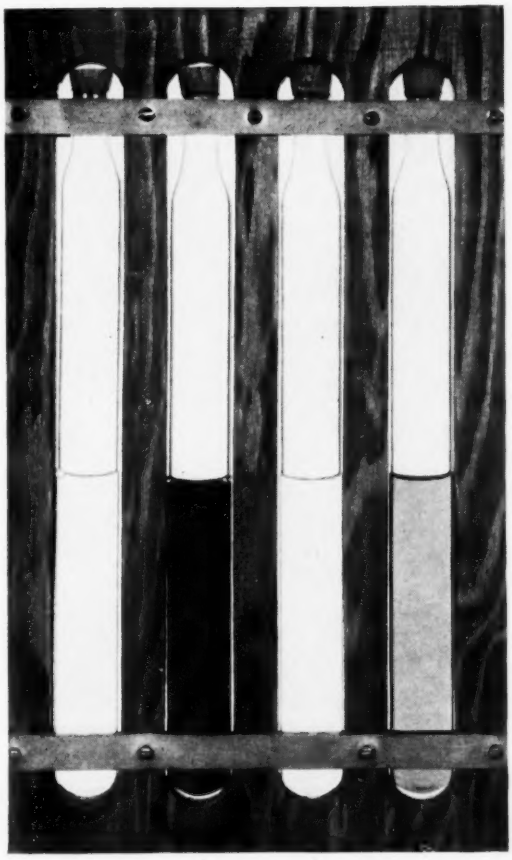


Fig. 12—New and oxidized turbine oils from A.S.T.M. oxidation test:
1. New straight mineral turbine oil.
2. Same oil after 72 hrs. Neutralization number of straight mineral oil at this stage reached maximum allowable 2.0.
3. New inhibited turbine oil E.
4. Inhibited turbine oil E after 870 hrs. Neutralization No. 0.5.

as certain rustproof compounds, pipe thread compounds, cutting oils, etc., will likewise contaminate the oil and adversely affect its service life. The elimination of such contaminants by the use of a proper turbine cleaning procedure will greatly reduce oil maintenance problems.

The Additive Is Not a Cure-all

No possible combination of additives can act as a substitute for proper cleaning, flushing, and maintenance. This is a particularly important factor under emergency conditions such as in wartime when severe schedules, overload operations, and scarcity of experienced operating personnel may result in poor maintenance practices which will greatly increase the rate of oil deterioration.

Nor can rust-inhibited oils prevent rust formation in parts of the turbine system with which they do not come in contact. Therefore, even with inhibited oils, some traces of rust may be found in certain portions of the lubricating system not regularly reached by the oils, such as sump and storage tank roofs unless these latter are treated with a rust preventive.

THE PROCEDURE OF RECONDITIONING

In order to keep a turbine oil in service, products of oxidation, polymerization and contamination must be removed continually. There are a variety of ways for removing such oil deterioration products; all are contingent upon two basic types of equipment:

1. Reconditioning by methods which can only remove insoluble materials.
2. Reconditioning by methods which not only remove insoluble sludges, but also the soluble products.

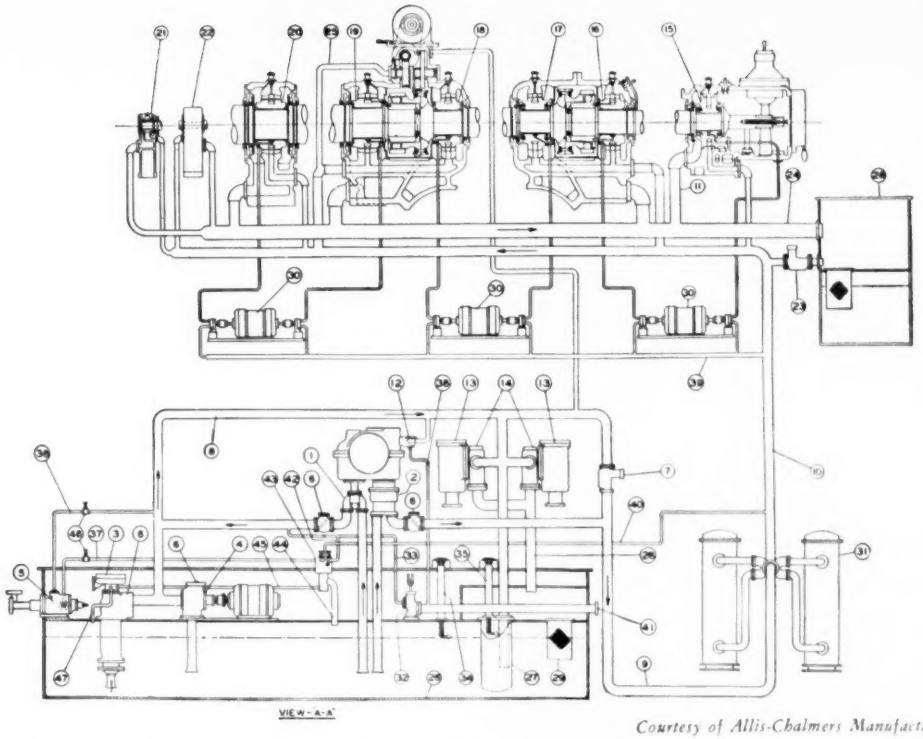
Settling

The simplest and most readily accomplished means of effecting at least partial clarification of a used turbine oil is to allow it to stand quietly in some form of settling tank for a period of several days or even weeks. During this time, and depending on the efficiency of the settling and any decanting facilities, it is generally possible to remove suspended insoluble oxidized material, foreign particles, dirt and water. Separation of such oil contaminants is accomplished by gravity alone.

The equipment available for settling will control the effectiveness of the procedure. Good practice in turbine design is to provide rest tanks, so arranged that two batches of oil are available which can be alternated in use. By means of bottom draw-offs, adjustable pump-out lines or manual decanting of the clear oil (in smaller units), the clarified oil is separated from the settled materials. Settling is most effective in flat or horizontal tanks of minimum depth.

Settling may be accomplished at any temperature. Some authorities believe that, where time will permit, thorough clarification is gained without heating coils; probably the best results are obtained at temperatures of around 120-140° F., depending upon the time available for settling. Excessively high temperatures should be avoided to prevent the possibility of accelerating oxidation. Practically no settling will occur while the oil is being heated, because of the convection currents created. Conversely, settling at low temperatures should be avoided because the rate of separation is retarded in a cold-thickened oil.

There are disadvantages to reconditioning oil by settling and decantation just as there are advantages. The disadvantages include:



Courtesy of Allis-Chalmers Manufacturing Co.

Fig. 13—Oiling system for an Allis-Chalmers condensing opposed double-flow tandem compound impulse reaction steam turbine generating unit.

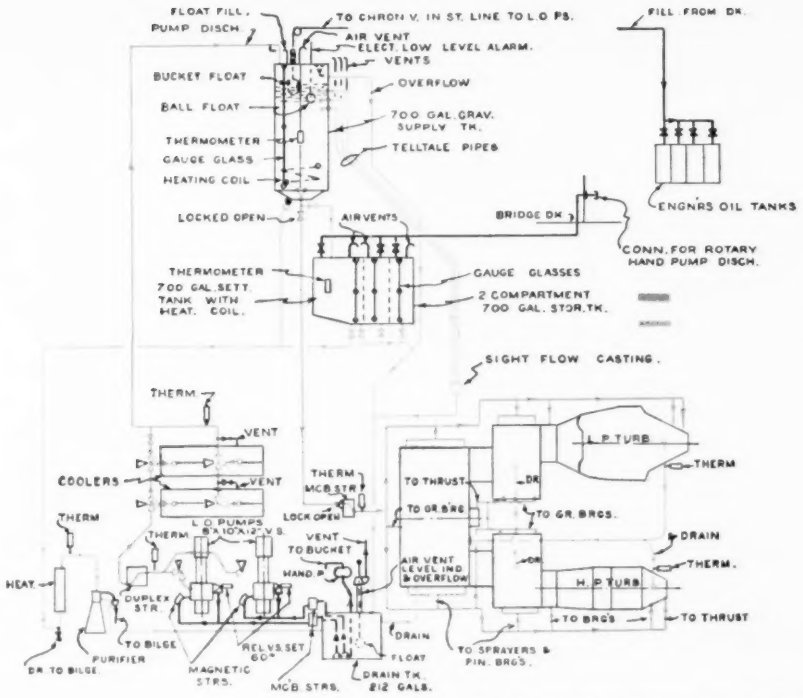
1. Main oil pump for governor.
2. Main oil pump for bearings.
3. Auxiliary oil pump, steam driven.
4. Auxiliary oil pump, motor driven.
5. Automatic pressure regulator.
6. Check valves.
7. Relay oil relief valve.
8. Relay oil supply pipe.
9. Bearing oil supply pipe to cooler.
10. Bearing oil supply pipe from cooler.
11. Thrust and oil drain.
12. Power oil relay.
13. Power cylinder.
14. Power cylinder oil relay.
15. Combined No. 1 journal and Kingsbury thrust bearing.
16. No. 2 journal bearing.
17. Combined No. 3 journal and low pressure Kingsbury thrust bearing.
18. No. 4 journal bearing.
19. No. 5 journal bearing.
20. No. 6 journal bearing.
21. Exciter bearing.
22. Exciter bearing.
23. Bearing oil relief valve.
24. Bearing oil drain system.
25. Turning gear lubricating oil supply.
26. Oil reservoir.
27. Accumulator.
28. Relay oil drain pipe.
29. Oil strainer.
30. H.P. lubricating system.
31. Oil coolers.
32. Oil dump valve.
33. Relay pressure line to dump valve.
34. Oil level indicator.
35. Accumulator oil level indicator.
36. Pressure regulator connection to relay pressure.
37. Pressure regulator connection to bearing pressure.
38. Oil pressure to mechanism for closing inlet valves.
39. Oil supply to H.P. oil pump.
40. Bearing oil supply to sight feed valve assembly.
41. Relay oil connection to bleeder line check valve.
42. Relay oil supply to sight feed valve assembly.
43. Sight feed valve assembly.
44. Sight feed valve overflow pipe.
45. Steam driven auxiliary oil pump lubrication supply line.
46. Hand valves.
47. Steam driven auxiliary oil pump lubrication drain (2).

1. The necessity for two complete batches of oil.
2. The turbine must generally be shut down for change-over.
3. Considerable space is required for settling tanks.
4. While a batch of oil is in service, impurities are not removed as they collect, but are permitted to build up to some predetermined concentration, at which time the batch is withdrawn and purified.
5. Only insoluble contaminants are removed. The oil may still contain soluble oxidation and polymerization products.

Centrifugal Treatment

Centrifuging improves the stability of a turbine oil in service by removing undissolved contaminants or foreign matter. Centrifuging involves the same basic principles as settling and decantation, but is faster because the separating force is several thousand times that of gravity.

The centrifuge effectually frees an oil of suspended insoluble oxidizing material, foreign mineral matter, dirt and water; also, as stated, some of the soluble oxidation products. The latter applies chiefly, however, to mineral acids or those organic acids which are more soluble in water than oil.



Courtesy of Newport News Shipbuilding and Dry Dock Company

Fig. 14—Oiling diagram for a Newport News Marine Turbine. Oil to bearings is shown in red; oil to drains is shown in green.

These may be removed if water is added along with the oil being centrifuged.

A centrifuge will not separate liquids which are mutually miscible. As with settling and decantation, separation of oil contaminants is made according to gravity, accelerated by centrifugal force, and is effective with any oil containing such impurities.

The term "capacity", as applied to a centrifuge, often is used loosely. A centrifuge may be said to have two capacities:

1. *Through-put capacity,* which is the total quantity of oil that can be put through the machine regardless of the degree of purification effected and without overflowing.
2. *Effective capacity,* which is the quantity of oil that can be put through the machine with the desired degree of purification.

Effective capacity, generally, has no relation to through-put capacity, but it is of chief interest to the turbine operator. Effective capacity depends upon used oil viscosity; temperature; amount, size and weight of impurities; degree of purification desired; and persistency of emulsion if water is present.

An oil purification centrifuge should always be set to operate by the two-liquid discharge method. This does not necessarily mean that water should be added at the centrifuge, but the discharge opening should be provided to emit any water which may be in the oiling system.

Centrifuging is often referred to as "wet" or "dry" according to whether or not water is intentionally added to the oil at the centrifuge. Sometimes this is inconvenient and somewhat dangerous, but when it will work, cleaner oil will result from the addition of water to the oil at the centrifuge. Centrifuging "wet" has the following advantages:

1. The washing effect of water aids in the removal of impurities.
2. The water carries away the lighter impurities which have a gravity approximately that of water, permitting longer runs between cleanings.
3. Some acids which are apt to form in lubricating oil are more soluble in water than petroleum oil and are thus removed, reducing oxidation catalysis.

The objections to centrifuging "wet" include:

1. Due to the greater density of water, the water discharge must be lower than the oil discharge to permit water to flow out of the centrifuge. Therefore, if the water seal breaks, oil will flow out of the lower water discharge, instead of the oil discharge. If not noted by the operator or if safety devices are not installed, the centrifuge may take all of the oil out of the system since the centrifuge should take suction from the bot-

tom of the tank through a sight overflow which is designed to prevent lowering of the oil level.

2. If periodic cleaning of the centrifuge is neglected, the discharge outlets may plug up, causing the centrifuge to fill with water, which will pass to the turbine system through the clean oil discharge.
3. Clean oil and water will not ordinarily emulsify. If the oil becomes unusually dirty, emulsion may occur, the addition of water in such cases should be discontinued.

In a centrifuge bowl during operation, a ring of oil is formed surrounded by a ring of water. The circular metal ring on top of the bowl prevents that portion of the water under it from overflowing. The wider this ring or water dam, the wider the ring of water in the centrifuge bowl. The dividing line between oil and water, called the "water line", is not directly beneath the inside edge of the water dam because it is pushed outward by the centrifugal force of the oil underneath the dividing wall.

Oil Filtration

Oil filters are best adapted to force-feed lubricating systems. According to the nature of the filtering element, they are capable of removing insoluble oxidized material, foreign mineral matter, water, dirt, and in some cases, oil-soluble oxidized material.

1. Filters of the metallic or mechanical type involving edge filtration, copper ribbons, steel wool, screens or strainers, remove coarse contaminants such as metal chips and particles of grit and scale. Insoluble oxidized material is generally not removed unless the size of the particles is sufficiently large to be caught by the filter element openings. Nor can soluble oxidized material, finely divided carbon particles, water, dust, and the finer insoluble oxidized materials be removed by such filters.
2. Filters of the bag type, or filters composed of absorbent material, not only remove coarse contaminants but go a step further by removing more of the finely divided insoluble oxidized material. Certain of these filter materials also remove mineral acids as well as water. Filtration is accomplished by adhesion of contaminants to the surfaces of the filtering material.
3. Adsorbent type filters contain fuller's earth boneblack, charcoal, or some active type of clay. In addition to removing coarse and fine contaminants, filters of this type remove to some extent soluble oxidized material and water. In such filters, oil contaminants do not only adhere to the surfaces of the filtering material, but also actually penetrate. This may be a disadvantage when dealing with an oil containing a chemical additive, such as an inhibited turbine oil, for the filtering material may remove the oxidation or corrosion-retarding additive. Obviously an adsorbent type filter should, therefore, be carefully studied before it is applied to a turbine lubricating system.

Limiting Characteristics

Steam turbine oils which are kept properly conditioned by centrifuging, filtration, or a combination of these treatments, can be continued in service as long as they meet the following specifications:

Water, %	0.1 Max.
Neutralization No.	1.5 Max.*
Precipitation No.	0.01 Max. (dry)
Ash, %	0.01 Max.
Corrosion, Copper Strip	Negative
Viscosity	As per manufacturer's recommendation for the particular unit or as normally used in unit.

*Where the Neutralization Number is known to have risen abruptly in the previous three months this limit should be halved. Where the Neutralization Number is known to have risen slowly over two or more years service this limit may be doubled.

Where reconditioned or used turbine oils are to be placed in turbine service as a fresh fill to the system, the discharge should be watched closely for a short time thereafter to see that the oil is clean.

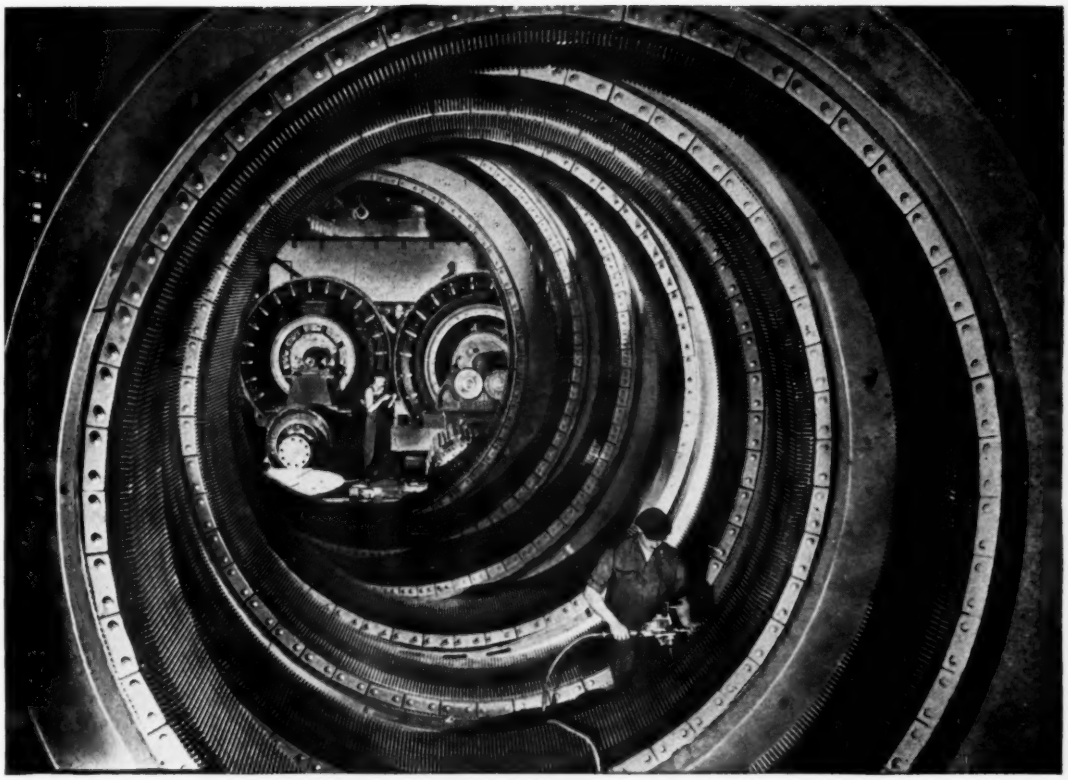
Caution

The above limits are *maximum* with respect to each item, and they should seldom or ever be approached if the turbine system is properly maintained.

CONCLUSION

Lubrication of turbine bearings was involved in some of the earliest research engaged in by the Petroleum Industry. From the beginning, turbine bearings have been of the conventional sleeve type, commonly known as plain bearings. Consequently the theory of lubrication as developed during this period of research was applicable to turbine bearings, and of material assistance when bearing dimensions, rate of oil flow and oil viscosity had to be figured based upon expected loads, speeds and temperatures.

With these structural and operating conditions established, the petroleum research investigator could proceed with his study of turbine oil stability on a strictly chemical basis. Subsequent correlation of these data with service performance has proved most effectually the value of cooperative research.



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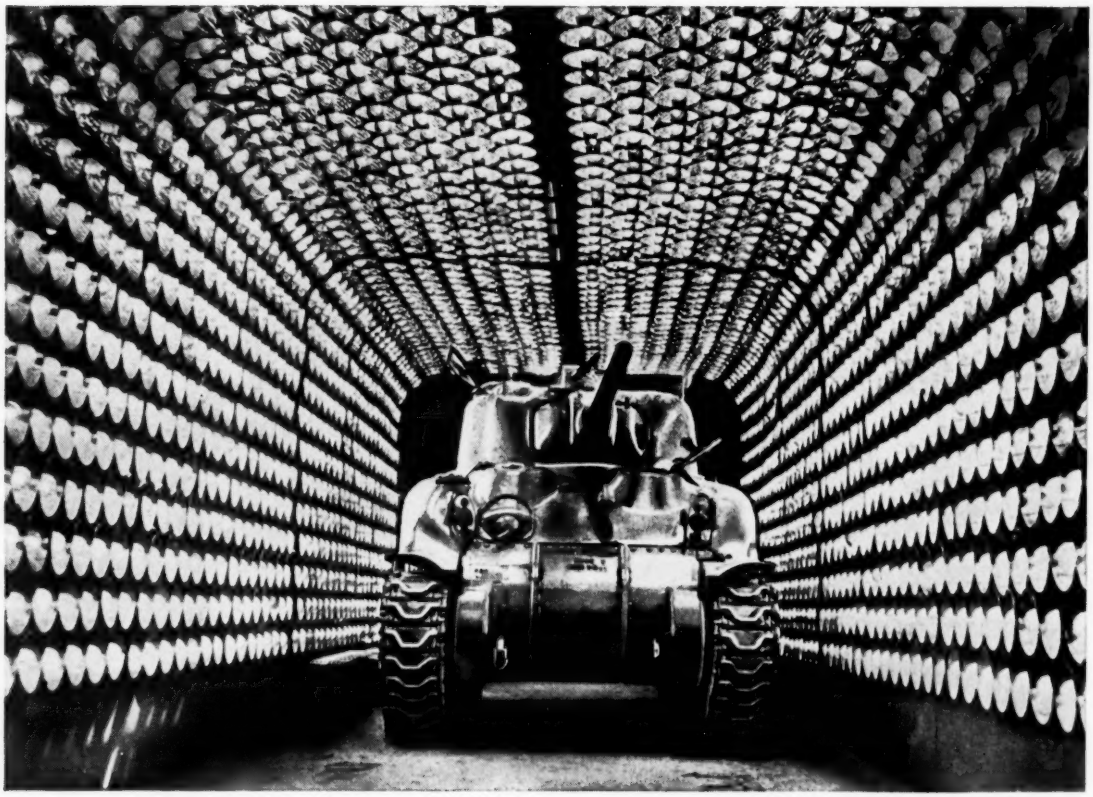

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